Remarks on Delta Action 8 Workshop of May 27, 2005

Ken Newman, June 14, 2005

1 Summary of recommendations

For easier reference the recommendations made throughout this report are summarized here. Sections 5 and 6 include additional thoughts regarding alternative analysis procedures.

1. If feasible, simultaneous acoustic tagging of hatchery and wild juvenile salmon should be carried out in order to study the degree of similarity between hatchery and wild fish in terms of survival and behavior.
2. Continue to try to keep export levels relatively constant throughout the period of time it takes releases to reach Chipps Island.
3. Explore the possibility of calculating an integrated measure of exports over the time period when outmigrants should be most influenced by exports. (Bryan Manly's work that led to choosing exports over the first three days after release is an example of this kind of exploration.)
4. Select export levels at the boundaries of possible values to shorten the time required to learn about the potential export effect on survival.
5. Statistical analyses comparing survival rates between different release groups under different experimental conditions should include different variance terms. For example, linear regressions of survival rates against exports should be fit using, at a minimum, weighted least squares.
6. Use embedded replicate tag codes within each release group to provide a means of detecting overdispersion.
7. Allow for potential overdispersion when carrying out statistical analyses, and adjust standard errors appropriately.
8. Make releases below Chipps Island timed to coincide with the arrival of upstream releases (i.e., pairing upstream and downstream releases) so that survival probability can be distinguished from capture probability.
9. Consider the possibility and/or implications of carrying out a split-plot type analysis of the DA 8 experiments.
10. Consider covariate adjustment in the analysis of the relationship between survival and exports in order to partially control for confounding factors.
11. Make additional releases at previously observed levels of exports to provide information to help control for confounding factors. Determining just how many replicates should be done and for which export levels will take some additional analysis.
12. Carry out analyses to estimate potential shock effect.
13. Use both Chipps Island and ocean recoveries when trying to make inference about survival between upstream locations and Chipps Island.
14. Use "paired" downstream releases (at Port Chicago or anywhere near Chipps Island) with each "block" of upstream releases to evaluate the assumption of common Chipps Island capture probabilities.

15. For "paired' releases (upstream and downstream release groups) study the ocean catch distribution (in terms of time and area) to determine the degree of evidence for similar ocean recovery probability π.

16. Compare estimates of p from Sherman Island releases with paired release-based estimates of p_r and p_{gs}.

17. Write down underlying statistical models for how information on Sacramento and Vorden releases are incorporated.

18. Consider integrated approaches to modeling survival as a function of exports.

19. Investigate the applicability of proportional hazard models for studying the effect of exports on survival.

20. Carry out additional "power" analyses, perhaps in the framework of integrated models, to evaluate the information gained from various combinations of exports and to evaluate the number of years of studies required to detect a particular assumed export effect.

21. Lend support and/or "added value" to the acoustic tagging project, perhaps by placing more acoustic tag detectors in the central Delta, e.g., just beyond the DCC.

2 DA 8 studies from the perspective of classical experiment design features

The primary objective of the Delta Action 8 experiments is to quantify the effects of water exports from SWP and CVP facilities on the survival of juvenile salmon outmigrating during the late fall and winter months (November through February).

The experimental protocol has been as follows: (a) to externally mark and internally tag hatchery fish, where single tag codes are used for large groups of fish, (b) to later truck and release fish in various locations upstream of (e.g., Sacramento, Vorden), in (Georgianna Slough), and adjacent to (Ryde) the central Delta, and then (c) to recover some of the fish with a midwater trawl at Chipps Island and to later recover some fish in the samples taken from the ocean fisheries.

There are a number of issues, some obvious and some less so, relating to the general objective and to the experimental protocol that are worth discussing. I begin with a classical perspective of experiments where there are at least three components, experimental units, factors (combinations of which are treatments), and one or more response variables. A fourth component of some designs is blocking, the grouping together of homogeneous experimental units to reduce experimental error. In a standard randomized block design, the experimental units within each block are randomly assigned to one of the treatments.

The way the DA 8 studies have been carried out, these components could be viewed as follows:

1. Experimental units: a group of hatchery-reared juvenile salmon released with the same tag code
2. Factors: export level and release location
3. Response variables: recoveries at Chipps Island and in the ocean fisheries
4. Blocks: time periods when releases are made (usually a 3-4 day period within a given year)

Note that the export level factor is a continuous variable, not categorical nor discrete, but to simplify discussion I will for the moment treat it as if it were categorized.

2.1 Experimental units: groups of hatchery-reared juvenile salmon

The central issue here is the suitability of hatchery fish to serve as proxies for wild fish. Wild or naturally produced juvenile salmon, in particular the wild late fall and winter runs, are the salmon of primary concern. Acquiring information directly on the survival of wild salmon, however, is difficult to impossible; e.g., the endangered status of the winter run restricts intentional capture for marking or tagging. Hatchery juveniles are used instead as proxies and this begs the question of just how representative hatchery fish are in terms of survival.

At a minimum what is hoped is that the relative survival rates under different conditions, say survival rates when exports are 1000 cfs vs when exports are 5000 cfs, are roughly the same for both hatchery and wild fish. For example, suppose wild fish entering the central Delta have a 90% chance of survival when exports are 1000 cfs and a 60% chance when exports are 5000 cfs, while hatchery fish entering the central Delta survive at rates of 60% and 40% under the same respective conditions; the relative survival is 1.5 in both cases.

However, as pointed out by John Williams at the Workshop, the question of just how representative hatchery fish are of wild fish remains. The question will remain unanswered until juvenile hatchery and wild fish can be monitored simultaneously. The recovery rates at Chipps Island and in the ocean fisheries in the DA 8 studies are relatively low, and simply applying the DA 8 protocol to wild fish could require marking and tagging a prohibitively large number of fish to get enough recoveries for sufficiently precise estimates of survival rates.

For example, suppose as many as R=25,000 wild outmigrating juvenile winter chinook could be tagged and marked by Red Bluff Diversion Dam (ignoring ESA related restrictions on doing so) and further suppose survival to Chipps Island was S=0.8 and Chipps Island capture rate was p=0.002 (values have been estimated to be around 0.0016). Assume (to begin) a binomial distribution for the number of recoveries, y, i.e., $y \sim$ Binomial(R, Sp), where R is release number. The expected number of recoveries is $\mathrm{E}[y] = R * S * p = 40$, and the standard deviation is $R * Sp * (1 - Sp)$=39.8. To simplify calculations, suppose p was known, thus survival could be estimated by $y/(Rp)$, which has a standard error of $\sqrt{S(1 - Sp)/Rp} = 0.13$. To study the variation in estimates of S, the recovery process was simulated 10,000 times. Estimates of S ranged from a low of 0.34 to a high of 1.26 (5.3% of the time estimates exceeded 1.0), the middle 90% of values was [0.60,1.02]. Thus even with R=25,000 marked fish and an assumed known capture rate at Chipps Island, the estimate of S is not that precise. The use of ocean recoveries would increase precision (how they are used is described later), but still a relatively large number of wild fish would likely need to be caught and marked.

The upcoming acoustic tag studies described by Steve Lindley have a lot of potential for gaining more detailed information with smaller sample sizes. I don't recall if these studies will involve wild fish, but if they did, it could be quite valueable to simultaneously apply acoustic tags to wild and hatchery fish of similar size and maturity and release both groups from the same upstream locations.

Recommendation 1: If feasible, simultaneous acoustic tagging of hatchery and wild juvenile salmon should be carried out in order to study the degree of similarity between hatchery and wild fish in terms of survival and behavior.

2.2 Factors: exports and release locations

As was discussed at the Workshop, the exports factor is a troublesome variable to both control and to define. While a particular level of exports, say 4,000 cfs, may be specified for a particular set of releases, it is not easy to keep exports at that level throughout the entire period the released fish are enroute to Chipps Island. The underlying complication is that the "export treatment" occurs over a period of time. What can happen is that releases in two different years, say, were both made "at" 4,000 cfs but the export profile over time could have been quite different.

Recommendation 2: Continue to try to keep export levels relatively constant throughout the period of time it takes releases to reach Chipps Island.

Recommendation 3: Explore the possibility of calculating an integrated measure of exports over the time period when outmigrants should be most influenced by exports. (Bryan Manly's work that led to choosing exports over the first three days after release is an example of this kind of exploration.)

I have said this before, and I recognize some of the logistical and practical barriers to this, but "selecting" export levels at the extremes of what is possible will speed up learning just how much impact exports have on survival.

Recommendation 4: Select export levels at the boundaries of possible values to shorten the time required to learn about the potential export effect on survival.

2.3 Response variable: recoveries at Chipps Island and in ocean fisheries

For the current experiment protocol, the ideal response variable would be the actual number of fish surviving to Chipps Island. The achievable response variables are the number of surviving fish that are caught at Chipps Island or recovered later in the ocean fisheries' catch samples. (In Section 6 more finely specified response variables are discussed.)

Here I consider three issues related to the analysis of these response variables: (1) the need to account for different variances for different release groups; (2) the need to account for overdispersion; (3) the need to separate out or control for capture probability when studying survival.

1. *Role of release number in variance of $\hat{S}$.* The number of fish in a given experimental release as well as the survival (S) and capture (p) probabilities affect the variance of estimates of survival, $\hat{S}$. For example, again assuming a binomial distribution for the number of recoveries at Chipps Island, the variance of the number of recoveries is RSp, and the variance of $\hat{S}=y/(Rp)$ (assuming for simplicity that p were known) is $S(1-Sp)/(Rp)$. When making comparisons of $\hat{S}$ between different releases or when modeling $\hat{S}$ as a function of covariates, such as exports, the fact that variances differ between release groups needs to be incorporated into the comparisons or models.

   Recommendation 5: Statistical analyses comparing survival rates between different release groups under different experimental conditions should include different variance terms. For example, linear regressions of survival rates against exports should be fit using, at a minimum, weighted least squares.

2. *Overdispersion and variance estimates.* Recoveries at Chipps Island likely do not follow a binomial distribution exactly because of potential schooling (thus dependence between fish) and heterogeneity in the capture probabilities. Ocean recoveries come from fishery catch samples and estimated recoveries are stratified random sample expansions of these recoveries, thus observed and estimated recoveries will not exactly follow binomial distributions. As a result, both recoveries at Chipps Island and ocean recoveries likely have variances that are larger than what would be observed for binomial random variables, i.e., have extra-Binomial variation or, in general, what is called overdispersion. If overdispersion is ignored, standard errors are biased low.

   Embedded replicate tag codes are a useful tool for detecting overdispersion. For example, suppose a release of 40,000 fish is to be made and 4 different embedded replicate tag codes are used, 10,000 fish getting one of the 4 codes. The variation between observed recovery rates, y/R, for each of the 4 groups can then be compared to the expected variation under the binomial distribution, and can thus provide an estimate of overdispersion and a more realistic estimate of variance.

Recommendation 6: Use embedded replicate tag codes within each release group to provide a means of detecting overdispersion.

Previous analyses of the fall run experiments (Newman and Rice 2002; Newman 2003) have have included an overdispersion parameter to account for this larger variation, and it seems reasonable to allow for the same with the DA 8 experiments.

Recommendation 7: Allow for potential overdispersion when carrying out statistical analyses, and adjust standard errors appropriately.

3. *Separating p from S.* The capture probability p varies with time as the midwater trawl cannot operate continuously throughout the outmigration period. The problem in terms of estimating S is to somehow separate the effect of p from S. There have been at least four methods used to attempt to separate or control for the effect of p:

   (a) Assume that p is proportional to a measure of sampling effort based on area of the river swept by the trawl and length of time spent trawling, label this f_i for release group i. Then $y_i/(R_i f_i) \propto \hat{S}$, where $\hat{S}$=#survivors/R_i.

   One difficulty with the implementation of this method has been the way f has been calculated. The time period for calculating the area-time measure begins with the first capture and ends with the last capture. Assuming some fish have arrived before the first capture and some have arrived after the last capture but have eluded capture, the f is underestimated.

   (b) Assume that p is the same for releases made in the same time-interval and calculate a ratio of estimated survival rates, $(y_1/R_1)/(y_2/R_2) = \widehat{S_1/S_2}$. This begs the question of equal p, however. (Note: a variation on this and the previous method has been used in some of the analyses, e.g., $(y_1/(R_1 f_1))/(y_2/(R_2 f_2))$.)

   (c) Release marked and tagged fish just upstream of the Chipps Island trawl (Sherman Island), assume 100% survival to Chipps Island, and thus estimate p from y/R. A potential difficulty with this estimate is that arrival distribution of these fish may only partially cover the time period of arrivals for releases made further upstream or in the central Delta.

   (d) Release marked and tagged fish just downstream of the Chipps Island trawl (Port Chicago) and use information on ocean recoveries to estimate p, or more critically, to estimate the absolute value of S. Letting y_{ur} and y_{uo} denote Chipps Island recoveries and ocean recoveries of fish released above Chipps Island and y_{do} denote ocean recoveries of fish released below Chipps Island,

$$\widehat{S} = \frac{y_{ur} + \hat{y}_{uo}/\hat{\pi}}{R_u}, \quad \text{where}$$
$$\hat{\pi} = \frac{\hat{y}_{do}}{R_d}$$

   There are two caveats about this method. Note the hats above y_{uo} and y_{do} to denote estimated recoveries, based on expansions of catch sample recoveries, pooled over three years of ocean recoveries and many different catch regions. As mentioned previously, estimation of ocean recoveries introduces overdispersion in the estimate $\widehat{S}$. Secondly, there is the implicit assumption that the ocean recovery rate, denoted by π, is the same for upstream and downstream releases.

   Release specific estimates of p can also be calculated:

$$\hat{p} = \frac{y_{ur}}{y_{ur} + \hat{y}_{uo}/\hat{\pi}}$$

   This allows a check on the assumption of equal p for releases made during the same time period (in the same "block"); and in the cases of releases made from Sherman Island, allows a comparison with those estimates of p.

Despite the caveats with the fourth method, I consider it the best of the current methods for accounting for the affect of p.

Recommendation 8: Make releases below Chipps Island timed to coincide with the arrival of upstream releases (i.e., pairing upstream and downstream releases) so that survival probability can be distinguished from capture probability.

2.4 Blocking: time periods with multiple releases

In the DA 8 studies, the idea behind making releases at two or more locations within a relatively short time window, is to ensure that the releases are identical, or more realistically, relatively homogeneous in terms of their downstream experience, differing primarily in their release locations. A more subtle issue is that the export levels are meant to be essentially the same during the outmigration period for releases made in the same time window, thus export levels are potentially confounded with time periods.

Thus, the DA 8 study design is not a standard randomized block design in that the blocks, or time periods, coincide with single (targetted) export levels. I think the design can be viewed as a split plot design with exports being a whole plot factor and release sites being a split-plot factor. The table below contrasts a randomized block design with two blocks with a split-plot design assuming there are two release sites and three export levels (Low, Medium, and High) and two replicates of all six treatment combinations.

Randomized Block Design

Block 1				Block 1			
	Low	Medium	High		Low	Medium	High
Site 1	Trt1	Trt2	Trt 3	Site 1	Trt 1	Trt 2	Trt 3
Site 2	Trt4	Trt5	Trt 6	Site 2	Trt 4	Trt 5	Trt 6

Split Plot Design with 2 replicates

Low	Medium	High	Low	Medium	High
Site 1	Site 1	Site 1	Site 1	Site 1	Site 1
Site 2	Site 2	Site 2	Site 2	Site 2	Site 2

Recommendation 9: Consider the possibility and/or implications of carrying out a split-plot type analysis of the DA 8 experiments.

2.5 Other issues

1. *Confounding factors.* Confounding factors are factors which influence the response variable and differ in value between different levels of the experiment factors. For example, when comparing non-smokers with smokers (the treatments) in terms of survival (the response variable), age can be a confounding variable. If one does a study where all the non-smokers are in their 70s and all the smokers are in their 20s, then the percentage still alive one year later will likely be higher amongst smokers than non-smokers. Age is a confounding variable here. It is associated with survival and differs in level between the treatment groups (older for non-smokers and younger for smokers).

   Confounding factors thus have the potential of *confusing* the relationship between treatments and the response variable. In the context of DA 8 studies, suppose flows have a positive relationship with survival (as previous analyses by Newman and Rice 2002, and Newman 2003 suggest), and suppose exports between 4,000 and 10,000 cfs had no effect when flows were above 8,000 cfs. If export levels were at 10,000 cfs when flows were 20,000 cfs and exports were at 4,000 cfs when flows were at 8,000 cfs, then it would appear that lowering export levels lowered the survival rate relative to higher export levels. Other potential confounding factors include release temperature and Delta Cross-Channel (DCC) gate position.

Ideally one carries out a randomized experiment design where many experimental units are randomly assigned to treatments and confounding factors are in effect controlled for because the values of the potential confounding factors are the same on average for all the treatment groups. With the DA 8 studies this is not practical, however. This could take years to do. One can attempt to at least partially control for such confounding factors by carrying out an analysis of covariance, i.e., including covariates, such as flow and release temperature, in models for survival. Relatedly, replication at previously tested levels of exports can be useful because the values of confounding factors, such as flow, could differ for the same export levels.

Recommendation 10: Consider covariate adjustment in the analysis of the relationship between survival and exports in order to partially control for confounding factors.

Recommendation 11: Make additional releases at previously observed levels of exports to provide information to help control for confounding factors. Determining just how many replicates should be done and for which export levels will take some additional analysis.

2. *Shock effect.* Another issue, related to the fact that hatchery fish are being used as surrogates for wild fish, and are being transported and then released into the river at various locations, is the notion of a shock effect. A "shock" effect is defined as mortality over and above what would be observed for an otherwise identical fish that had been in the river throughout its life and was just passing the release point at the same point in time. Explanations for shock include a sudden temperature differential and disorientation. As I estimated previously (Newman 2003), this shock mortality could be relatively large, thus biasing low estimated recovery rates unless the shock effect can be separated out (with paired releases and certain assumptions this is possible (Newman 2003)).

   Recommendation 12: Carry out analyses to estimate potential shock effect.

3 An idealized view of different release-recovery designs

In this section products of binomial and trinomial distributions are used to model the number of recoveries of tagged salmon for various release-recovery designs. These probability distributions are simplified approximations for the real distributions for recoveries since they do not include overdispersion and do not account for factors that potentially confound estimation of survival. However, these relatively simple distributions are useful for answering *some* of the questions raised by Pat Brandes in her summary report included in the background information for the Workshop. Also these distributions serve as building blocks for more realistic probability models.

Approximately five different release-recovery designs have been used throughout the DA 8 studies so far. The five designs are described below along with corresponding binomial and trinomial distributions for recoveries.

The notation R is for number released, y for number recovered, S for survival probability, p for capture probability at Chipps Island, and π for probability of recovery in an ocean fishery. Subscripts referring to release locations are r, gs, si, s, v for Ryde, Georgiana Slough, Sherman Island, Sacramento, and Vorden, respectively; and subscripts referring to recovery locations are d and o for downstream (Chipps Island) and ocean. Releases at Port Chicago are denoted by the subscript d also, since those locations are relatively close to Chipps Island.

- *Design 1, Upstream releases at Ryde and Georgianna Slough; Recovery downstream*

$$
\begin{aligned}
y_{r,d} &\sim \text{Binomial}(R_r, S_r p) & (1)\\
y_{gs,d} &\sim \text{Binomial}(R_{gs}, S_{gs} p) & (2)
\end{aligned}
$$

- *Design 2, Upstream releases at Ryde and Georgianna Slough; Recovery downstream and in ocean fisheries*

$$
\begin{aligned}
y_{r,d}, \hat{y}_{r,o} &\sim \text{Trinomial}(R_r, S_r p, S_r(1-p)\pi) & (3)\\
y_{gs,d}, \hat{y}_{gs,o} &\sim \text{Trinomial}(R_{gs}, S_{gs} p, S_{gs}(1-p)\pi) & (4)
\end{aligned}
$$

- *Design 3, Upstream releases at Ryde and Georgianna Slough and downstream release at Port Chicago; Recovery downstream and in ocean fisheries*

$$
\begin{aligned}
y_{r,d}, \hat{y}_{r,o} &\sim \text{Trinomial}(R_r, S_r p, S_r(1-p)\pi) & (5)\\
y_{gs,d}, \hat{y}_{gs,o} &\sim \text{Trinomial}(R_{gs}, S_{gs} p, S_{gs}(1-p)\pi) & (6)\\
\hat{y}_{d,o} &\sim \text{Binomial}(R_d, \pi) & (7)
\end{aligned}
$$

- *Design 4, Upstream releases at Ryde, Georgianna Slough, just above Chipps Island at Sherman Island, and downstream release at Port Chicago; Recovery downstream and in ocean fisheries*

$$
\begin{aligned}
y_{r,d}, \hat{y}_{r,o} &\sim \text{Trinomial}(R_r, S_r p, S_r(1-p)\pi) & (8)\\
y_{gs,d}, \hat{y}_{gs,o} &\sim \text{Trinomial}(R_{gs}, S_{gs} p, S_{gs}(1-p)\pi) & (9)\\
y_{si,d}, \hat{y}_{si,o} &\sim \text{Trinomial}(R_{si}, p, (1-p)\pi) & (10)\\
\hat{y}_{d,o} &\sim \text{Binomial}(R_d, \pi) & (11)
\end{aligned}
$$

- *Design 5, Upstream releases at Sacramento, Vorden, Ryde, Georgianna Slough, Sherman Island, and downstream release at Port Chicago; Recovery downstream and in ocean fisheries*

$$
\begin{aligned}
y_{s,d}, \hat{y}_{s,o} &\sim \text{Trinomial}(R_s, S_s p, S_s(1-p)\pi) & (12)\\
y_{v,d}, \hat{y}_{v,o} &\sim \text{Trinomial}(R_v, S_v p, S_v(1-p)\pi) & (13)\\
y_{r,d}, \hat{y}_{r,o} &\sim \text{Trinomial}(R_r, S_r p, S_r(1-p)\pi) & (14)\\
y_{gs,d}, \hat{y}_{gs,o} &\sim \text{Trinomial}(R_{gs}, S_{gs} p, S_{gs}(1-p)\pi) & (15)\\
y_{si,d}, \hat{y}_{si,o} &\sim \text{Trinomial}(R_{si}, p, (1-p)\pi) & (16)\\
\hat{y}_{d,o} &\sim \text{Binomial}(R_d, \pi) & (17)
\end{aligned}
$$

The key parameters of interest are the survival rates (the S's) between upstream release locations and Chipps Island. For each of the five designs the formulas for calculating maximum likelihood estimates of survival or survival ratios are given; in some cases formulas for delta method estimates of the variances are also shown. The variance formulas can be used to determine the effect on precision of estimates of S of changing release numbers and/or increasing the capture rate at Chipps Island (p); although simulations can be used for this purpose, too.

- *Design 1.* Absolute survival rates cannot be estimated with this design but the recovery rates, Sp, for both releases can be estimated.

$$
\begin{aligned}
\widehat{S_r p} &= \frac{y_{r,d}}{R_r}\\
\widehat{S_{gs} p} &= \frac{y_{gs,d}}{R_{gs}}
\end{aligned}
$$

Assuming identical capture rates for both releases, the ratio of Georgianna Slough to Ryde survival rates can be estimated:

$$\widehat{\frac{S_{gs}}{S_r}}_1 = \frac{y_{gs,d}/R_{gs}}{y_{r,d}/R_r} \tag{18}$$

The variance using the delta method:

$$V\left[\widehat{\frac{S_{gs}}{S_r}}_1\right] \approx \frac{R_r^2}{R_{gs}^2}\left[\frac{R_{gs}S_{gs}p(1-S_{gs}p)}{(R_rS_rp)^2} + \frac{(R_{gs}S_{gs}p)^2(1-S_rp)}{(R_rS_rp)^3}\right] \tag{19}$$

An estimate of the variance given sample data:

$$\hat{V}\left[\widehat{\frac{S_{gs}}{S_r}}_1\right] = \frac{R_r^2}{R_{gs}^2}\left[\frac{y_{gs,d}(1-y_{gs,d}/R_{gs})}{y_{r,d}^2} + \frac{y_{gs,}^2(1-y_{r,d}/R_r)}{y_{r,d}^3}\right] \tag{20}$$

- *Design 2.* Again only relative survival rates can be calculated.

$$\widehat{\frac{S_{gs}}{S_r}}_2 = \frac{(y_{gs,d}+\hat{y}_{gs,o})/R_{gs}}{(y_{r,d}+\hat{y}_{r,o})/R_r} \tag{21}$$

To gain an intuitive understanding of the rationale behind Eq'n (21), plug in the expected values:

$$\begin{aligned}\frac{(y_{gs,d}+\hat{y}_{gs,o})/R_{gs}}{(y_{r,d}+\hat{y}_{r,o})/R_r} &\approx \frac{S_{gs}p+S_{gs}(1-p)\pi}{S_rp+S_r(1-p)\pi}\\ &= \frac{S_{gs}(p+(1-p)\pi)}{S_r(p+(1-p)\pi)} = \frac{S_{gs}}{S_r}\end{aligned}$$

Again using the delta method, the variance for the estimated ratio can be calculated:

$$\begin{aligned}\hat{V}\left[\widehat{\frac{S_{gs}}{S_r}}_2\right] &= \frac{R_r^2}{R_{gs}^2}\left[\frac{1}{(R_rS_r(p+(1-p)\pi))^2}\left(R_{gs}S_{gs}\left(p(1-S_{gs}p)+(1-p)\pi(1-S_{gs}(1-p)\pi)\right)\right)\right]\\ &+ \frac{R_r^2}{R_{gs}^2}\left[\frac{(R_{gs}S_{gs}(p+(1-p)\pi))^2}{(R_rS_r(p+(1-p)\pi))^4}\left(R_rS_r\left(p(1-S_rp)+(1-p)\pi(1-S_r(1-p)\pi)\right)\right)\right]\\ &- 2\frac{R_r^2}{R_{gs}^2}\left[\frac{1}{(R_rS_r(p+(1-p)\pi))^2}R_{gs}S_{gs}pS_{gs}(1-p)\pi\right]\\ &- 2\frac{R_r^2}{R_{gs}^2}\left[\frac{(R_{gs}S_{gs}(p+(1-p)\pi))^2}{(R_rS_r(p+(1-p)\pi))^4}R_rS_rpS_r(1-p)\pi\right]\end{aligned} \tag{22}$$

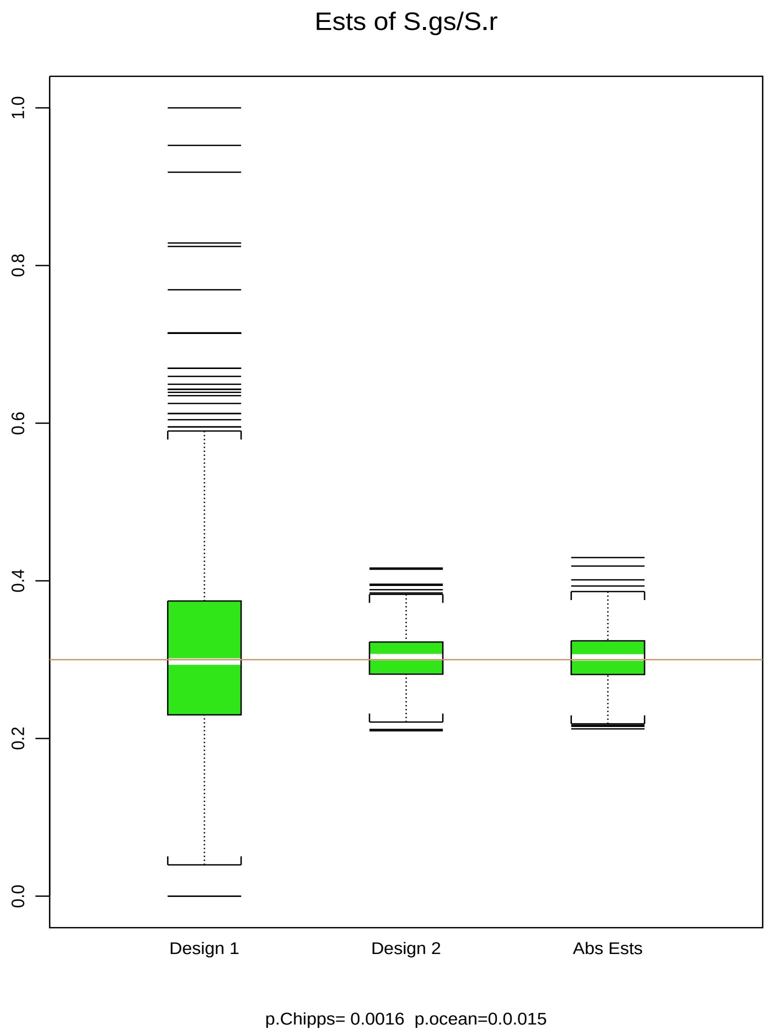
In practice an estimate of the variance could be determined by plugging in observed values similar to what was done for Design 1.

I have not worked out analytically the gain in precision made by using the ocean recoveries but simulation results clearly demonstrate the reduction in variability in estimates of the ratio of survival rates. Figure 1 contains boxplots of estimates of the ratios under Designs 1 and 2[1]. The reduction in variance due to the inclusion of ocean recoveries can be considerable. Note that the apparent gain in the figure is somewhat exaggerated, however, in that the overdispersion due to estimated ocean recoveries is not included.

Recommendation 13: Use both Chipps Island and ocean recoveries when trying to make inference about survival between upstream locations and Chipps Island.

[1] The median of estimated Chipps Island capture rates from an analysis of fall run studies is 0.0015 while the estimated ocean recovery rate is about ten times larger, 0.016.

Figure 1: Boxplots of simulated estimates of ratio of S_{gs} to S_r based on data from different designs. Design 1 uses Chipps Island recoveries only, while Design 2 uses Chipps Island and ocean recoveries. The Absolute Estimates boxplot is based on Design 3 data and uses downstream releases to estimate the absolute values of S_{gs} and S_r first, and then takes the ratio. The true value is 0.3 and is shown by the horizontal line across the plot. Boxplots are based on 1000 simulations with R_r=50,000, R_{gs} = 70,000, E[p]=0.0016, E[π]=0.015.



- *Design 3* Absolute survival rates can be estimated in this design (and in Designs 4 and 5).

$$\widehat{S}_r = \frac{y_{r,d} + \hat{y}_{r,o}/\hat{\pi}}{R_r} \tag{23}$$

$$\widehat{S}_{gs} = \frac{y_{gs,d} + \hat{y}_{gs,o}/\hat{\pi}}{R_{gs}} \tag{24}$$

$$\widehat{\pi} = \frac{\hat{y}_{d,o}}{R_d} \tag{25}$$

Then the ratio of survival rates can be estimated by

$$\widehat{\frac{S_{gs}}{S_r}}_3 = \frac{\hat{S}_{gs}}{\hat{S}_r} \tag{26}$$

The delta method could again be applied to estimate the variance of this estimate but I have not done so here.

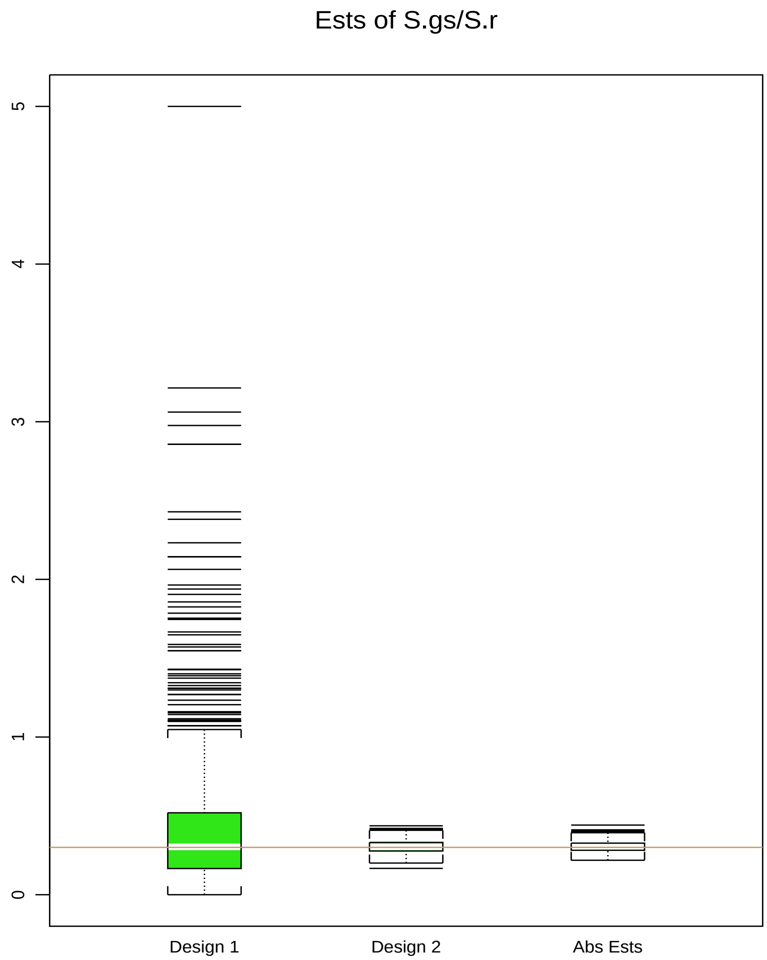
The rationale for these estimates can be seen by substituting the expected values into each of the terms. For example referring to Eq'n (23),

$$\begin{aligned}\frac{y_{r,d} + \hat{y}_{r,o}/\hat{\pi}}{R_r} &\approx \frac{R_r S_r p + (R_r S_r (1-p)\pi)/(R_d \pi/R_d)}{R_r} \\ &= \frac{R_r S_r p + R_r S_r (1-p)}{R_r} = S_r p + S_r(1-p) = S_r(p + 1 - p) = S_r\end{aligned}$$

Assuming that the capture rates at Chipps Island are the same for both releases, for estimating the ratio of Georgianna Slough to Ryde survival rates, it turns out, perhaps surprisingly, to be statistically more efficient to not use Eq'n (26). Instead it is better to use Eq'n (21) from Design 2. I have not worked out the exact details as to why this estimator is more efficient (has a smaller standard error) than using the ratio of estimated absolute survival rates, but simulations have demonstrated that the standard errors are smaller with Eq'n (21). For example, simulations under one set of values showed that the standard error was about 5% larger when working with Eq'n (26) (compare the right two boxplots in Figure 1). One reason is likely the fact that π is not being estimated with Eq'n (26).

On the other hand, if the p's differ, i.e., $p_r \neq p_{gs}$, then Eq'n (26) should be used. Figure 2 is based on simulations where the p's randomly vary within a "block" of upstream releases but are on average the same. Estimate Eq'n (18) from Design 1 is particularly unstable and biased high, while estimates from Design 2 (utilizing ocean recoveries) are relatively unbiased but more variable, a 14% increase in standard error, than Eq'n (26).

Figure 2: Boxplots of simulated estimates of ratio of S_{gs} to S_r based on data from different designs when the capture rate at Chipps Island differs between paired Georgianna Slough and Ryde releases. The true value is 0.3 and is shown by the horizontal line across the plot. Boxplots are based on 1000 simulations with R_r=50,000, R_{gs} = 70,000, E[p]=0.0016, E[π]=0.015.



Comments:

1. As stated previously, I like this design because of its potential for separating survival probability from capture probability. Relatedly, the assumption that capture rates are the same for releases made in the same "block" (e.g., simultaneous releases at Ryde and in Georgianna Slough) can be checked (and formally tested by a likelihood ratio test), by calculating release-specific estimates of p. For example, for Ryde and Georgianna Slough:

$$\begin{aligned}\hat{p}_r &= \frac{y_{r,d}}{y_{r,d} + \hat{y}_{r,o} R_d / \hat{y}_{d,o}} \\ \hat{p}_{gs} &= \frac{y_{gs,d}}{y_{gs,d} + \hat{y}_{gs,o} R_d / \hat{y}_{d,o}}.\end{aligned}$$

   Recommendation 14: Use "paired" downstream releases (at Port Chicago or anywhere near Chipps Island) with each "block" of upstream releases to evaluate the assumption of common Chipps Island capture probabilities.

2. If in fact p is the same for both Ryde and Georgianna Slough, the common p can be estimated by maximum likelihood. However, I've not determined if a closed form solution exists, or if it must be solved numerically.

3. The assumption of common ocean recovery rates, π, for upstream and downstream releases is crucial but difficult to verify. The ocean recovery rate patterns, however, can at least be examined; e.g., using a cluster analysis of recoveries by time and area for releases from multiple "blocks" of releases to see if variation between blocks is greater than variation within blocks.

Recommendation 15: For "paired' releases (upstream and downstream release groups) study the ocean catch distribution (in terms of time and area) to determine the degree of evidence for similar ocean recovery probability π.

- *Design 4.* The additional releases at Sherman Island provide a means of independently estimating the capture rate, p, at Chipps Island, i.e.,

$$\hat{p}_{si} = \frac{y_{si,d}}{R_{si}}. \quad (27)$$

Given this estimate, downstream releases at Port Chicago are in principle not necessary for estimating the absolute survival rates; e.g., $\hat{S}_r = y_{r,d}/(R_d \hat{p}_{si})$. However, given Port Chicago release information, formal statistical tests for equality of the Sherman Island estimate (Eq'n 27) with estimates of p_r and p_{gs} as described above for Design 3 can be carried out.

Estimates of survival or the ratio of survival rates can be calculated as for Design 3.

Recommendation 16: Compare estimates of p from Sherman Island releases with paired release-based estimates of p_r and p_{gs}.

- *Design 5.* With releases from Sacramento and Vorden added, their respective absolute survival rates S_s and S_v can be estimated separately (using the same procedure as described in Design 3). Additionally release-specific capture rates at Chipps Island, p_s, p_v, p_r, and p_{gs} can be estimated.

One of the aims of this design is to assess Steamboat and Sutter Sloughs' effect on downstream migrants given that some Sacramento releases could pass through these sloughs and thus be less likely to enter the central delta. I'm not exactly sure of the intent of Vorden releases, however, but again believe it is related to the issue of how likely it is that outmigrating juveniles enter the central delta. What is needed, perhaps, is more clarification regarding exactly how information from these additional releases is used. Hence, the next recommendation:

Recommendation 17: Write down underlying statistical models for how information on Sacramento and Vorden releases are incorporated.

4 Release numbers, sampling rates, and precision

With reference to some of Pat Brandes' questions, I did a small amount of work looking at the effect on precision of estimates of S_r/S_{gs} by changing release numbers and/or increasing recovery effort at Chipps Island. Design 3 was assumed with $p_r = p_{gs}$, and Eq'n (21) was used. S_r was set at 36% and S_{gs} was 30% of S_r, thus S_{gs}/S_r=0.30. Doubling the release numbers at Ryde and Georgianna Slough, i.e., R_r=100,000 and R_{gs}=140,000, reduced the standard error only slightly from about 0.032 to about 0.031.

Using a more optimistic S_r=0.8 and S_{gs} still equalling 30% of S_r, the standard error went from 0.021 to 0.015 when release numbers were doubled.

Doubling the effort at Chipps Island had the same effect as doubling release numbers.

Although Design 1 and its estimator (Eq'n (18)), which does not use ocean recoveries, is not recommended, it is useful to note that doubling release numbers lowered the standard error from 12% to 8% (when S_r=0.36). This is further evidence for the importance of using ocean recoveries when estimating the survival ratio, i.e., the precision gain is sizeable, e.g., from 12% to 3.2%, and money is being saved by not spending more to increase the release numbers.

A related question is how to allocate a fixed number of fish to the different release locations. For example, considering Design 3 and given 170,000 fish, say, how should the fish be allocated between Ryde, Georgianna Slough, and Port Chicago? Assuming that p_r=p_{gs} and that absolute survival was not of interest, then no fish would need to be allocated to Port Chicago. Making this assumption in advance of seeing data, however, is not recommended. So suppose $p_r \neq p_{gs}$ but on average they are the same, and consider the estimate based on the ratio of estimated survival rates (Eq'n (26)). The table below shows the effect of varying allocations on the standard error of the estimate (results are based on simulated data, S_r=0.8, $S_{gs} = 0.3 * 0.8$, and releases are in 1000s of fish).

R_r	50	70	10	60	60	100
R_{gs}	70	50	120	90	100	60
R_{pc}	50	50	40	20	10	10
Std Err	0.022	0.024	0.031	0.021	0.019	0.022

I am not necessarily recommending the next to last combination because this analysis is rather limited (e.g., not considering the effect of exports, relatively arbitrary choice of S_r, etc), but it does point the way to further, more realistic analyses.

5 Modeling survival as a function of exports

The fundamental question remains how to determine the relationship between exports and survival and I only address this briefly here. I see three general issues: (1) determining the statistical model for the relationship; (2) defining the covariates, especially exports; (3) comparing study designs in light of the statistical model (e.g., power).

5.1 Models for survival

The problem is to specify a general statistical model to link a covariate, exports, with a response variable, recoveries, or more directly, to specify a model such that survival is a function of exports (and other covariates).

5.1.1 Two-step procedures

The procedures presented at the Workshop and shown in the background materials are a two step procedure: first the survival ratio is estimated, then a linear regression of the survival ratio on exports is fit. For example, referring to Eq'ns (23) and (24),

$$\begin{aligned}
\widehat{S}_{gs} &= \frac{y_{gs,d} + \hat{y}_{gs,o}/\hat{\pi}}{R_{gs}} \\
\widehat{S}_{r} &= \frac{y_{r,d} + \hat{y}_{r,o}/\hat{\pi}}{R_{r}} \\
\frac{\hat{S}_{gs}}{\hat{S}_{r}} &= \beta_0 + \beta_1 Exports
\end{aligned}$$

This procedure is simple and may tell the same general story as more complicated procedures, so I hesitate to state unequivocally that more complicated methods are needed. I will list a few alternatives, however.

If a two step procedure is used, (1) use ocean recoveries (either Eq'n (21) or Eq'n (26) to calculate the survival ratio; (2) use weighted least squares to fit the linear regression where the weights are the inverses of the (estimated) variances of the survival ratio estimator; (3) consider including additional covariates that may be confounding the relationship (e.g., flow, release temperature. The inclusion of additional covariates may be somewhat limited given the number of observations, and potential correlations between other covariates and exports.

5.1.2 Integrated procedures

An integrated, single step procedure, similar to what was done for the fall releases (Newman and Rice 2002 and Newman 2003), could be carried out. For example, number of recoveries would be modeled directly as a function of exports. Referring to the "paired" release analysis of the fall run (Newman 2003) and Design 3, and repeating the model description given earlier:

$$\begin{aligned}
y_{r,d}, \hat{y}_{r,o} &\sim \text{Trinomial}(R_r, S_r p, S_r(1-p)\pi) \\
y_{gs,d}, \hat{y}_{gs,o} &\sim \text{Trinomial}(R_{gs}, S_{gs} p, S_{gs}(1-p)\pi) \\
\hat{y}_{d,o} &\sim \text{Binomial}(R_d, \pi),
\end{aligned}$$

where

$$\log\left(\frac{S_i}{1-S_i}\right) = \beta_0 + \beta_1 I_{GS} + \beta_2 Exports + \beta_3 I_{GS} * Exports + \ldots + \beta_k X_k.$$

with i=r or gs. This model allows for the possibility that Ryde is affected by exports (though that assumption could be dropped); the term X_k generically denotes other covariates. Such models ignore overdispersion but methods similar to those done for paired release analysis of the fall run could be used here.

Recommendation 18: Consider integrated approaches to modeling survival as a function of exports.

A very speculative suggestion is to consider the suitability of Cox's proportional hazard models (a Google search brings up several web sites with explanations). Similar models have been used to model the downstream survival of outmigrating Columbia River salmon juveniles as a function of various environmental factors. I'm not sure, however, how well such models deal with such issues as overdispersion, use of estimated response variables, or "products" of distributions (e.g., binomial times trinomial).

Recommendation 19: Investigate the applicability of proportional hazard models for studying the effect of exports on survival.

5.2 Defining covariates

Determining just what measure of exports should be used is not a trivial problem As discussed at the Workshop Bryan Manly has investigated different time periods of measurements (3 days, 10 days, 17 days, for example) using linear models. Within the framework of alternative models just discussed, it might be worthwhile to carry out similar analyses, perhaps after adjusting out the effect of covariates.

As mentioned previously (Recommendation 6), developing an integrated measure of exports over the time period when outmigrants should be most influenced by exports may be worthwhile.

A related issue is the effect of "measurement" error in exports. Measurement error is more typically something referring to a static independent or predictor variable, e.g., the diameter at 4.5 feet of a tree. The effect of ignoring measurement error in linear regression is often to produce an estimated slope coefficient that is biased towards zero. I don't know how much of an issue that could be with exports, but it is worth thinking more about.

5.3 Experiment design

A key question raised by several at the Workshop, and a primary reason for the Workshop, was how much more data are needed to determine the export effect. Is there enough data now? How much value is there in gathering additional data in 2005? If there are not enough data now, how many more years of data are required?

To answer such questions, three things are needed: (a) a model for the relationship between exports and recoveries (or more directly survival), (b) guesses as to the nature of the true relationship, described in terms of model parameters, (c) analysis of how different data points (export levels) affect the precision of estimates of the corresponding parameters.

Component (a), a model, was discussed above. Given a model, a biometrician, with the help of knowledgeable fisheries biologists, could postulate a range of possible export effects to produce component (b). Lastly, given the model and range of effects, various designs (with differing levels of exports for varying numbers of years) could be evaluated. Certainly, as said before, designs which include exports at the extremes of the range of levels will yield the most information, but intermediate export levels are also necessary to detect nonlinearities in the relationship.

Recommendation 20: Carry out additional "power" analyses, perhaps in the framework of integrated models, to evaluate the information gained from various combinations of exports and to evaluate the number of years of studies required to detect a particular assumed export effect.

6 Other work

6.1 Recommended work

1. A more refined analysis of allocation of total number of fish to each of the main release locations could be carried out.

2. While not directly related to estimating the effect of exports on survival, procedures for calculating confidence intervals for survival ratios other than using $\pm$ 2 standard errors, say, need to be developed to allow for asymmetric confidence intervals. Relatively simple bootstrap type procedures may suffice.

6.2 Optional but potentially valuable work

One could consider more complex, detailed models which might not be necessary for addressing major questions of Workshop but could be used for potentially more accurate and powerful analyses of D8 data. The suggestions below are aimed at using the available data at a finer level, i.e., with less aggregation. In particular

1. Consider continuous time models that explicitly model travel time and the time Chipps Island trawl is operating where the response variables include time of individual fish recovery rather than just total recoveries.

2. Consider a less aggregated treatment of ocean recoveries, at least breaking down recoveries by age at recovery, to determine what is lost, if anything, by using total expanded ocean recoveries as a response variable.

3. Consider incorporating information on recoveries of tagged fish at the SWP and CVP pumping stations.

4. Acoustic tagging has potential to provide more details about the variety of fates of released fish. Even if capture probability was 100%, the exact time, location, and reason for the deaths of non-survivors would remain unknown. For example, suppose 10,000 fish were released just downstream of Sacramento and the DCC is open. Further suppose 8,000 fish survive to Chipps Island, the nature of the deaths of those 2,000 remaining fish is unknown. How many entered the central Delta through the DCC? The ideal response variable would be the eventual fate of an individual fish, in particular where, when, and why a given fish died. Such information is not possible with the current experiment protocol. However, the acoustic tagging project does make it possible to gain additional information about the probability a fish going down the mainstem Sacramento river enters the central Delta as well as information about place and time of death for some of the fish (assuming 100% or at least very high detection probabilities enroute to San Francisco Bay).

   Recommendation 21: Lend support and/or "added value" to the acoustic tagging project, perhaps by placing more acoustic tag detectors in the central Delta, e.g., just beyond the DCC.